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The Physiological and Perceptual Effects of Wrist Cooling During Exercise in a Thermal Environment

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The Physiological and Perceptual Effects of Wrist Cooling During Exercise in a Thermal
Environment

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B.S, The Ohio State University, 2016

Thesis

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Master of Science Thesis

The Physiological and Perceptual Effects of Wrist Cooling During Exercise in a Thermal Environment

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Abbreviations List

| | |
|------|------------------------------|
| Trec | Rectal Temperature |
| USG | Urine Specific Gravity |
| RPE | Rating of Perceived Exertion |
| BESS | Balance Error Scoring System |
| W1 | One Wristband Group |
| W2 | Two Wristbands Group |
| CON | Control Group |
| REC | Recovery Group |
| Tsk | Skin Temperature |
| WPD | Pooled Device Group |
| WPN | Pooled No Device Group |
| DR | Device-wearing group |
| NDR | Non-device |
| SL | Single Leg |
| TS | Tandem Stance |

Abstract

Purpose: This study examines the physiological effects of rectal temperature, skin temperature, heart rate, blood lactate, and the perceptual effects of ratings of perceived exertion, thermal sensation, fatigue, and thirst while wearing a cooling wristband during a cycling exercise protocol in an uncompensable heat stress environment. A secondary purpose was to examine the previously mentioned effects during a post-exercise recovery period. **Methods:** Fourteen recreationally active male subjects (Age: 22 ± 4 , Height: 181.6 ± 6.9 , Weight: 75.4 ± 8.7 , VO_2Max : 53.1 ± 7.2) biked on a cycle ergometer between 50-60% and 70-80% VO_2max intervals across four exercise trials in an environmental chamber (ambient temperature, 40°C , relative humidity 40%). **Results:** Significant differences were found in the cooling of rectal temperature during the recovery period for device wearing groups compared to non-device wearing groups (Mean $0.33^\circ\text{C} \pm 0.51^\circ\text{C}$, $P = 0.010$). Additionally, differences were observed between non-wearing groups and recovery only groups for rectal temperature (Mean: $-0.27^\circ\text{C} \pm 0.31$, $P = 0.023$). **Conclusions:** Our results suggest that regardless if the cooling wristband is worn during exercise, when the band is worn during recovery it can lower rectal temperatures faster than passive rest. No benefits were seen when wearing the wristband during exercise.

Keywords: Cooling, Cooling modality, Heat, Wrist, Wearable technology

Review of the Literature

I. Introduction

Athletics, and exercise in general, requires effort that often pushes the human body to its limits. Whether anaerobically or aerobically, the body must sustain effort in order to meet demands and achieve the results desired. The surrounding environment in which exercise takes place can further exacerbate this exertion. Climate (e.g. cold, hot, humid), and high altitudes are just some examples of stressful environments in which exercise can take place. Warm and hot environments are especially common for sporting competition and exercise to take place in. The affect of heat on the human body has been well studied with hot environments have being shown to reduce the functional capacities of the cardiovascular, thermoregulatory, and nervous systems.^{5,6,9,15,18,21} All of these afflictions accumulate together to negatively affect exercise performance.^{18, 28} Two leading theories on why and how a hot environment affects performance are the critical temperature theory and the anticipatory theory.^{19, 40} While both theories propose different mechanisms that decrease performance, both agree that any method of cooling that can lower body temperature can delay these adverse effects. If done successfully, cooling can diminish the rise in body temperatures, heart rates, and blunt perceptual measures of exertion and thermal sensations. The timing of cooling is also of importance with, pre-cooling, cooling during exercise, and post-cooling all having shown to incur different results.^{17, 23}

The aim of this review is to compare and contrast the physiological, perceptual, and performance effects of cooling modalities. The following modalities are included in

this review ice vests, neck collars, palm cooling devices, cooling garments, and research utilizing a mix of modalities. All of these devices and methods are currently available to the athletes and recreationally active individuals, and are well represented in the literature. Cooling modalities thus far have shown mixed results in being able to attenuate performance, physiological, and perceptual parameters. The need to find the most practical and effective means of cooling an athlete in the field setting that is easily accessible, convenient, and effective is an area worth exploring. Based on the literature, the current relevance of factors thought to benefit the most by cooling modalities are established in the following categories of performance, physiological, and perceptual responses.

II. Methods

For the purposes of this review, the following inclusion criteria needed to be met.

- One or more measurements of: rectal temperature, skin temperature, performance measures, heart rate, thermal sensation or comfort, and rating of perceived exertion.
- Contain an aerobic or anaerobic exercise protocol
- Exercise must be in a warm and/or humid environment (~25°C or higher)

For the purposes of this review, the following exclusion criteria were utilized.

- Protocol included passive heating
- Disabled or otherwise “unhealthy” participants
- Environmental conditions under 25°C

Electronic online databases of PUBMED, MEDLINE, and SPORTSDiscus were searched for all relevant literature. Furthermore, bibliography from the relevant literature

was scanned for additional references. After scanning abstracts and keywords, all relevant literature was thoroughly reviewed.

III. Thermoregulation and Heat Acclimatization

The human body is remarkable in its ability to adapt under stressful environments. Physical activity in the heat places the entire body under stress more so than ambient temperatures. When an active person commences exercise in a hot environment all organ systems, especially the nervous and cardiovascular systems, are placed under stress. This is caused by a combination of heat produced from the body during exercise, and heat absorbed from the surrounding environment.⁴ In fact, during intense exercise, body heat is produced about 15 times greater than at rest from muscle activity.²⁴ This process goes on to affect the body's heat storage capabilities. The body's heat storage abilities are rather simple; when the body produces or absorbs heat at a rate greater than can be dissipated; the internal core body temperature rises. When heat is lost to the environment the temperature starts to lower. It has been shown mathematically with the following equation.

Heat Balance Equation⁴

$$S = M - (\pm \text{Work}) - E \pm R \pm C \pm K$$

Where (S) signifies heat storage, (M) is metabolic heat produced from working muscles and only contributes to heat gain. The human body does not utilize all the metabolic heat created, and the remaining heat needs to be given off through other pathways. Thus, ERCK of the heat balance equation are the pathways for lowering or raising body temperatures. Evaporation (E) is caused by sweat or water vapor changing phases on the skin cooling it in the process. This heat exchange pathway is the most

efficient way for the body to cool itself. However, evaporation is affected by humid conditions because when the air is already saturated with water vapor, lowering the ability of sweat to change phases to vapor. Radiation (R) causes heat to be lost via electromagnetic waves, moving heat from high to low. When ambient temperatures are higher than skin temperatures, heat is absorbed as opposed to dissipated due to the thermal gradient caused by radiation. Convection (C) is the loss or gain of heat from a liquid gradient. This gradient is present in the air, liquid, or bodily fluids. An example of this is interaction happens between core and skin temperatures. Table 1 shows that as the gradient decreases between the two objects (core and skin temperatures) skin blood flow increases as a result²⁹.

Table 1. Adapted from Sawka et al.

| Core Temperature (°C) | Skin Temperature (°C) | Gradient (°C) | Skin Blood Flow (1 min⁻¹) |
|----------------------------------|----------------------------------|----------------------|---|
| 38 | 30 | 8 | 1.1 |
| 38 | 32 | 6 | 1.5 |
| 38 | 34 | 4 | 2.2 |
| 38 | 36 | 2 | 4.4 |
| 39 | 30 | 9 | 1.0 |
| 39 | 32 | 7 | 1.3 |
| 39 | 34 | 5 | 1.8 |
| 39 | 36 | 3 | 2.9 |

Estimated whole-body skin blood flow requirements during prolonged severe running exercise at different core and skin temperatures.

Conduction (K) is the lowest of the heat exchange pathways in terms of amount of heat lost or gained, and works through direct contact between objects, such as

feet contacting the ground, or bodies contacting protective equipment.⁴ The heat loss pathway being used is highly dependent on the humidity and ambient air temperatures.

A process exists to enhance and assist with the heat loss pathways and thermoregulation, and therefore an individual's tolerance to the hot environments. When an individual is exposed to a naturally hot and humid environment (i.e. outdoors) it is called heat acclimatization. On the contrary, when the heat exposure is in a controlled setting (i.e. laboratory) that is called heat acclimation.⁵ As defined by Armstrong⁶ the process of heat acclimatization is a complex progression of central and peripheral physiological adaptations that can improve exercise performance and reduce thermal strain while in a hot environment.^{5, 6}

This process requires repeated exposure to hot conditions for 8-14 days with an exercise intensity of above 50% VO_2^{max} to see at least moderate results⁵. The adaptations of heat acclimatization are shown in Table 2.

Table 2. Adapted from Armstrong et al.

| Adaptation | Days of Heat Acclimatization Required |
|--|---------------------------------------|
| Heart rate decrease | 3-6 |
| Plasma volume increase | 3-6 |
| Renal sodium and chloride concentration decrease | 3-8 |
| Sweat sodium and chloride concentration decrease | 5-10 |
| Core body temperature decrease | 5-8 |
| Skin blood flow increase | 5-10 |
| Whole-body sweat rate increase | 8-14 |

Along with these adaptations, decreases in perceptual responses such as ratings of perceived exertion and thermal sensations also decrease with repeated exposure⁵. Kampman et al. further supports the effect of heat acclimatization on lowering rectal temperatures even at rest.²¹ The heart rate through exercise in multiple hot and humid conditions, resting rectal temperatures were lowered 0.25°C at rest prior to heat exposure, and 0.46°C at the end of an exercise protocol in the heat. However, this study notes that aerobic conditioning alone also lowers average body temperatures during exercise versus no training.²¹ These adaptations generated from heat acclimatization, lower heart rate, decreased rectal temperature, increase in whole body sweat rate, rectal temperature. have been shown to increase performance as it allows for the body to exercise more efficiently.^{4, 5, 18, 28}

The heat acclimatization process is not uniform; many factors have an effect on the rate and magnitude of adaptation. One of those factors is an individual's aerobic fitness. Athletes with a higher VO₂ max have been shown to acclimate faster than those with lower fitness.^{5, 21} It should be noted that the effect of heat acclimatization on the onset sweat is not transferable between varying conditions (i.e. a person acclimatized to hot ambient temperatures will commence sweating earlier and benefit more from evaporation than one in hot and humid conditions) this can possibly lead to a decrease in performance.²¹

IV. Uncompensable Heat Stress and Exercise Performance

The Pre-Optic Anterior Hypothalamus (POAH) area of the brain is responsible for integrating many neural pathways from the periphery, and maintaining a set-point body temperature.⁴ When body temperature rises, by skeletal muscles and outside factors like

the surrounding environment, thermoregulation is put into effect, and when temperatures fall heat gain is initiated. From the periphery, effector input originates from warm and cold receptors imbedded in the skin and are sent to the POAH. These receptors communicate to the POAH if the skin is being warmed or cooled by ambient temperatures, exercise, objects, rectal temperature. An example of this is heat being transferred from the working muscles to the blood, where the warmed blood returns to the core of the body to cause an increase in rectal temperature.

Uncompensable heat stress occurs when these thermoregulatory mechanisms are insufficient at mitigating body temperature rise, and is observed when the surrounding environment has a temperature usually above 25°C.⁴ The process begins with an increase in body temperature that is picked up by the POAH, this initiates an increased cutaneous blood flow to the skin for heat to be released by evaporation, radiation, or convection pathways.²⁴ This reaction shunts blood away from the organs to the working muscles and the skin for effective thermoregulation. However, this process causes a paradigm by starting a competition for blood flow distribution between the working muscles and skin. If the demands of exercise are high enough then working muscles will get the majority of blood, which in turn will cause an even higher rise in temperatures due to the skin being unable to dissipate heat⁴. The additive effects will eventually be detrimental to activity in a hot environment, leading to uncompensable heat stress.

In research by Sawka et. al, subjects were asked to exercise in two differing climates, a moderate climate of 21°C and in a hot climate of 49°C (uncompensable heat stress). Subjects exercised in these two trials under two conditions, unacclimated and heat acclimated after a heat acclimation protocol.⁴³ This study design allowed the researchers

to examine the effects of heat stress on aerobic fitness ($\text{VO}^2 \text{ max}$) both acutely and after a heat acclimation protocol. Their results concluded that, regardless of the individual's heat acclimation status, aerobic fitness was decreased when placed under heat stress.⁴³ One proposed theory for this decrease is the shunting of blood away from the central organs to the skin. While heat stress did decrease aerobic exercise between trials within conditions, heat acclimation did increase aerobic performance when comparing pre and post-acclimation $\text{VO}^2 \text{ max}$ values. In self-paced exercise under heat stress, the cardiovascular system will decrease in function. Cardiac output and stroke volume will decrease and heart rate will increase during exercise, much more so in a hot environment than a moderate or cool one.⁴⁴ Périard et al. observed this strain on the cardiovascular system occurring parallel with a decrease in power output in cyclists. Furthermore, in the same study, ratings of perceived exertion were statistically different during exercise in a hot condition of 35°C than in a moderate condition of 20°C.⁴⁴ Clearly, heat has detrimental effects of an exercising individual even when acclimated.

V. Theories of Heat's Effect on Exercise

As seen before, uncompensable heat stress affects performance and physiological structures. Exercise performance, the cardiovascular system, and even exercise perception are all negatively attenuated in the heat. Crewe et al. observed that performance is affected from the onset of exercise in the heat by an increase in initial ratings of perceived exertion.¹¹ As mentioned before, there exists a competition between working muscles and the skin for blood flow. However, this redirecting of blood flow is mostly likely not the only reason for the observed effects of heat.

In the literature there are two leading theories on the how and why heat gain affects the body and therefore exercise performance: (1) critical-temperature theory¹⁹, and (2) anticipatory theory³⁹. In the first theory, it is believed that each individual has a critical temperature point that once reached will decrease performance in order to prevent the development of any exertional heat illness. During prolonged exercise in the heat, Nybo et al. hypothesized that an increase in cerebral temperature may mediate the development of fatigue when hyperthermia temperatures are reached²⁷. The second theory is based on an anticipatory model, which states that the brain will anticipate the increase in temperature based on the level of effort required and adjust intensity in order to prevent heat illnesses from occurring. A.M Edwards et al. performed a study between two environmental conditions, one cool and one hot, and found that exercising in a hot environment increased the neural processing of environmental factors, greater arousal, and conscious awareness of impending exercise demands¹⁵. If these individuals are aware of their surrounding conditions and the exercise to come they can anticipate the exertion needed for exercise and the forthcoming effects of heat. It was also concluded that the frontal cortex of the brain can differentiate between exercise in differing conditions, and that this awareness could effect neural drive and therefore motivation.¹⁵ With the previous information in mind, it should be expected that decreasing body temperatures, and masking thermal input, via cooling would have positive effects in dealing with the detrimental effects caused by heat stress.

The next section will review modalities that have been investigated to determine their value for improving exercise performance in the heat. The modalities reviewed in the following sections are: cooling/ice vests, neck cooling/ice collars, palm cooling, and a

mixed modality approach. These modalities were chosen to represent accessible and practical cooling choices for participants of any activity.

VI. Exercise Performance and Cooling Modalities

It is well documented that the ability to perform prolonged exercise is impaired in the heat^{5, 6,9,15,18,21}. Total distance covered by participants in a study by Minett et al was less when no cooling was provided to participants. This was a sprinting protocol, showing that the heat affects even short running distances. Time to completion or exhaustion was affected in Gonzalez-Alonso et al study with trained cyclists.¹⁹ They concluded that a drastic increases in body temperatures caused trained cyclists to fatigue much faster than when body temperatures were manipulated. Time to exhaustion ranged from 28-63 minutes in this study, highlighting that if body temperature can be attenuated by some intervention exercise times can increase.¹⁹ As demonstrated in the study by Tucker et al. self-selected pace is reduced when an individual is introduced to uncompensable heat stress. Researchers set the distance (20km) in two trials, one in a moderate climate (15°C) and the other in a hot climate (35°C), and then allowed subjects to freely select cycling pace to complete the distance. The average time and power output for the moderate climate was 28 minutes with power outputs of 272 watts. When compared to the hot climate trial there was a significant decrease in both time to completion and power output (30 minutes and 255 watts respectively). It can be concluded that the cyclists chose to exercise at a slower pace in order to delay the negative effects of exercising in the heat.³⁹

The magnitude of hyperthermia experienced is largely dependent on the duration and intensity of exercise¹⁸. Cooling is thought to attenuate hyperthermia, either through

pre-cooling which will lower the starting point of the rectal temperature, or during exercise, which will attenuate the rise of temperature and delay the adverse physiological effects. Post-cooling also offers performance benefits by accelerating recovery between bouts of exercise^{7, 18}. Of the 16 reviewed articles, 13 dealt with performance measures, eight of those studies were aerobic or endurance exercise protocols and the remaining six were anaerobic. Endurance is defined in this review as a time to exhaustion, exercise time ≥ 60 minutes, or a distance ≥ 5 k.

One modality utilized in the review was palm cooling, and this method showed little promise in increasing aerobic performance in the heat.^{1, 20, 34} Scheadler reported that time to exhaustion was reportedly shortened with their palm-cooling device that was devised of a gel bladder, although, the device warmed very quickly and many benefits were short lived. However, it should be noted that most palm cooling studies have devices that apply subatmospheric pressure to further draw blood to the hand. The practicality of holding a cooling device while running was brought into question by Scheadler. One study was found to look at anaerobic exercise and palm cooling, Goosey-Tolfrey found an increase of about 14 seconds of maintain peak power output in able-bodied cyclists when hand cooling was provided for only 10 minutes. The method of hand and palm cooling is an area scarcely in the literature in terms of exercise performance. The results from Scheadler and Goosey-Tolfrey would suggest this method is not advantageous.^{20, 34}

While the palm cooling literature has displayed little benefit to performance, the cooling modality of neck collars display potential. Three studies used cooling neck collars with an aerobic endurance exercise protocol, two of which reported positive benefits. Tyler et al. demonstrated two studies with similar protocols, that over the course

of 75 minutes, the distance covered by runners is greater when wearing a light weight cooling collar; a 5.9% increase within subject when compared to the control.^{41, 42}

Furthermore, in both studies, Tyler demonstrated that replacing the cooling modalities mid-exercise does not provide any additional benefit to performance.⁴¹ One neck collar study by Sunderland et al. studied anaerobic performance through a repeat sprint protocol and saw positive changes mean power output. These performance changes occurred in the latter half of a sprinting protocol, where researchers observed an attenuation of 6% of peak power decreases compared to a control along with the 7% increase in mean power output all while wearing a neck cooling collar.³⁷

Cooling or ice vests are currently the most popular modality to provide cooling in sport. Arngrimsson reported a 14s increase in 5k times when a vest was worn during a 38 minute warm up prior to the race. However, Eijsvogels did not show any improvement to a 5k time trial when wearing a vest. The difference between the two studies lies in the ambient temperatures and temperatures of the vests themselves. Argrimsson performed the 5k protocol in 32°C temperatures with a vest that was stored in a freezer ($\leq 0^{\circ}\text{C}$) whereas Eijsvogels had ambient temperatures of 25°C and used a refrigerated ($\geq 6^{\circ}\text{C}$) vests starting at higher temperatures. The amount of heat gained is influenced by surrounding environment, so perhaps the hotter environmental temperature in addition to the cooler temperature of Argrimsson's vest is why they observed positive benefits whereas Eijsvogels did not.^{4, 7, 16} In fact, all of the reviewed cooling modalities that showed positive effects on performance were studied in ambient temperatures of $\geq 30^{\circ}\text{C}$, and sustained wearing the modality for an extended period of time (i.e. >30 minutes).

This supports the notion that cooling is most effective with increased time of exposure and magnitude of thermal strain experience.

VII. Physiological Responses and Cooling Modalities

Cooling modalities ability to increase performance have been demonstrated in the literature. However, whether the increase is due to physiological responses, such as a lower Rectal temperature, or if it is because of the masking of the receptors and deceiving the mind to perceive working in a cooler environment. The following section presents evidence from the reviewed articles on the physiological responses to the cooling modalities investigated. The specific physiological responses of heart rate, rectal temperature, and skin temperature were specifically looked for.

Schlader et al. investigated the effects of skin temperature on exercise intensity and found that skin temperature and exercise intensity were inversely related to one another at the onset of exercise³¹⁻³³. At the beginning of exercise initial skin temperature seems to be of the utmost importance as it is suggested to be one of the main modulators of intensity for the entire duration of exercise. Schlader proposes cooler skin at the onset of exercise will provide more blood to the working muscles as opposed to the periphery for thermoregulation. Six of the sixteen reviewed studies measured mean skin temperature and of those six, four of the studies resulted in increased performance. Minett studied various cooling modalities and found that over 20 minutes of cooling, the modalities that covered large surface areas (e.g. whole-body cooling and head with hands) provided lower Skin temperature and improved sprint performance. Although it was a short exercise duration, the redirection of skin blood flow through cooling may have helped distribute the blood back into the working muscles as Skin temperature

would have raised the gradient between core and skin³⁰. Eijsvogel's cooling vest study did lower skin temperature but failed to increase performance. However, as mentioned before, the thermal strain experience by those subjects may not have been great enough to shift the thermal gradient between skin and core (Table 1).

Metabolic heat is one of the main pathways for heat gain, as referenced in the heat balance equation.⁴ Regardless of the surrounding temperatures rectal temperatures rise concurrently with the metabolic rate. However, the environment serves to only further exacerbate the rise through the other pathways (ERCK).⁴ Causing a decrease in rectal temperature through practical cooling modalities is difficult, with only five studies showing rectal temperatures affected. Most commonly, rectal temperature is attenuated in its rise as opposed to decreased meaning temperatures still rise due to natural metabolic heat production, but the rate in which they rise is slower with cooling provided.²¹ Ice vests, and whole body cooling through mixed modalities were typically shown to attenuate the rise in Rectal temperatures during exercise^{7, 10,12,14,16,17}. The ice vest worn during warm-ups in Argrimsson's study showed that rectal temperatures increase slowly after application. It is thought that the initial lowering of rectal temperature allows for more heat storage and thus increases performance by not delaying the detrimental affects of high rectal temperature. When whole-body cooling was applied during Minnet's study, lower rectal temperatures were seen throughout the sprint protocol, which conserved sprint times and increased distance covered.

Lastly for palm cooling, Adams et. al. showed that post-exercise palm cooling can decrease rectal temperature faster than passive rest alone. However, while more significant than passive rest it still did not provide quick cooling rates. Other palm

cooling studies showed no physiological effects for their exercise protocols, but did not examine any recovery sessions.^{20, 34}

Decreasing rectal temperatures seems to largely be dependent on the amount of surface area cooled. In the reviewed articles ice vests, whole-body cooling, and a mixed modality approach all lowered or attenuated rectal temperature more so than cooling applied to local areas such as the neck, hands, or head. Cold water immersion is the gold standard for lowering the rectal temperatures of hyperthermic athletes, and is the best cooling modality to ensure survival of life-threatening heat illnesses such as exertional heat stroke. Yet, the practicality of this method is brought into question for non-emergent conditions². The amount of time required for this modality is too great when considering potential equipment removal, and time to dry off the body, along with patient comfort.

The redirection of blood to the skin for heat loss results in a decline central blood volume affecting the cardiac output during exercise.⁴ Since cooling can lower heart rates in the heat, it could indicate that the cardiovascular system is working more efficiently even with added thermal strain, thus maintain performance. As with rectal temperature it appears that surface area is related to attenuation in heart rate as whole-body cooling and chest cooling provided lower heart rates¹². Most of the studies showing increased performance^{41, 42} did so without observing any positive changes to heart rate. No neck cooling study showed significant changes in heart rate yet three still showed improvements in performance.

VIII. Perceptual Responses and Cooling Modalities

Sensory information about the temperature of surrounding environments is taken in by the periphery's warm and cold receptors across the body⁴. From that input, effort is

derived even from the onset of exercise. In fact, Cheung et al. demonstrated that by manipulating skin temperature, and therefore the receptors, perception of thermal strain experienced could be changed causing an increase in performance with trained cyclists⁹. Furthermore, Schlader et al. was able to change work output in cyclists by applying cooling menthol or a heating capsaicin gel. This change happened while observing no change in rectal temperature and controlling skin temperature, demonstrating that thermal perception is a powerful modulator of exercise intensity. Two studies showed no improvement of performance when thermal sense was lowered.^{14, 16} However the time and magnitude of their cooling protocol brings into question the efficiency of the cooling. Duffield provided a short cooling time of 25 minutes, and Eijssvogel's provided refrigerated cooling (at 6°C) as opposed to near freezing temperatures. DeMartini demonstrated that providing cooling for just 10 minutes can lower thermal sensation, and Fillinger showed up to 25 minutes of lower thermal response when cooling was provided during exercise possibly leading to improved performance. While some studies^{37,41} showed no lowering of whole body thermal sensation, local cooling sensations instead were decreased. Sunderland and Tyler showed no lowering of physiological responses or reductions in whole body thermal sensation with a neck cooling collar, but still observed performance increases. This brings evidence that even local sensations can have positive effects on the motivation of exercise, and perception of thermal strain experienced. In fact, regional differences of thermal comfort exist all over the body with some areas being more sensitive than others. When exposed to the heat, cooling applied to the face elicits ratings positive ratings of comfort and is highly sensitive to changes in temperature. The chest and abdomen do not elicit many changes in comfort when cooling

is applied during heat exposure, and individual's rate rather neutral responses.²⁵ It can be suggested from this that if a cooling modality's aim was to manipulate the wearer's thermal comfort and perception the cooling should be applied close to or on an area of high sensitivity like the face.

Another modulator of exercise is perceived exertion. Quantified by Borg, the rating of perceived exertion (RPE) is a category scale that allows subjects rate their effort of work on a likert scale ranging from 6 (e.g. very, very light) to 20 (e.g. very, very hard). The RPE scale has been thought to incorporate information from, the periphery, central nervous system, cardiovascular system, and respiratory system⁸. The perception of effort may be the connection between physiological parameters affected by exercise and behavioral changes required to maintain comfort and survival in the heat. Crewe et al. studied RPE in uncompensable heat stress by assigning three separate wattages, calculated from a percentage of peak power, during exercise trials with only temperatures changing. The authors found that it was the increases in temperature, more so than wattage, that caused a faster rise in the ratings of exertion. Moreover, it was shown that the faster the rise in RPE the faster trial would be terminated while exercising to exhaustion¹¹. RPE lowered in just six of the studies reviewed^{7,12,17,22,23,42}. Two neck cooling studies^{22,42} showed decrease in RPE whereas the other three did not^{3,37,41}. The same exercise protocol was used between two of Tyler et al's studies and both found differing results in terms of RPE. Even when statistically significant changes were reported for RPE's they were rarely ever clinically significant and did not vary more than one or two ratings in standard deviations. It would make sense that RPE is more difficult

to lower as it had been more connected to physiological responses, such as a rise in HEART RATE, more so than thermal sensation.^{8, 11}

IX. Summary

The findings of this review demonstrate that practical cooling modalities at best reduce responses of perception of effort more so than physiological responses^{7, 10,12,13,16,17,22,23,42}. Furthermore, it is the reduction of thermal sensation from the cooling modalities that causes increase of performance. Most of the reductions in thermal sensation coincide with decreasing skin temperature, thus manipulating the warm receptors embedded in the skin. While manipulating thermal perception with cooling modalities has shown promising results, it should be used with caution. Changing one's perception of effort and thermal sensation disrupts the body's ability to communicate when dangerous levels of heat storage are being reached. It is entirely possible that one could push the body to dangerous levels of heat gain causing heat illnesses like exertional heat stroke. Conversely, when Tyler studied the effect on continuous cooling via replacing a cooling collar, he concluded that perhaps this deception of skin receptors can only go so far before the body decreases performance regardless of the mind's perception.⁴¹ Indeed while thermal perception is a powerful modulator of exercise in the heat it is ultimately the cardiovascular system and rectal temperatures that will make modifications to performance in order to maintain safety⁴¹. Heat acclimatization is a natural process that can aid in thermoregulation and by lowering rectal temperatures, and provides a number of other ergogenic benefits (Table 2). Finding a practical cooling modality that offers lowering of physiological responses like rectal temperature and heart rate throughout exercise may be more beneficial over deceiving perception. Additionally,

the location of cooling also plays an important role. It has been shown that regions of the body respond differently to cooling²⁵. This review finds that the neck cooling^{3, 12,22,37,41,42} offers more benefits than palm cooling^{1, 20,34}, and that the more surface area covered the more likely it is to see positive responses in performance, perception, and physiological responses.

The timing of cooling was shown to have an effect on responses as well.^{17, 23} For athletes the timing of cooling, and volume²³ are of the up most importance. Pre-cooling and cooling at the onset of exercise seem to provide the most benefit as this will set the initial exercise intensity through manipulating sensory input, and translate into a longer workload.^{17, 23}

The mode of exercise seems to matter little as both aerobic and anaerobic exercise protocols benefitted from some type of cooling modality. Therefore, three important factors to keep in mind when choosing a cooling method are (1) the temperatures in which exercise will take place, (2) the duration of cooling, and (3) the magnitude of cooling. The greater magnitude of thermal strain experienced the more effective cooling will be. This is demonstrated in studies where participants attained higher rectal temperatures, and when exercise was conducted in higher ambient temperatures^{1, 7,12,14,17, 20, 22,37,40-42}. Secondly, regarding duration, the protocols with shorter durations observed benefits through slight masking of perceptions, but hardly saw performance benefits^{13, 14}. Lastly, those studies that provided the greatest magnitude of cooling (i.e. greater surface area covered and colder temperatures) consistently observed positive effects. This is demonstrated in and between cooling vest studies, these studies provided consistent benefits, and one thought postulates it is due to the surface area covered. Additionally,

between cooling vest studies, the colder vests (i.e. those stored in a freezer or contained ice) caused more beneficial results when compared those kept in cooler (i.e. refrigerated) conditions.^{7,16}

X. Conclusion

In the current state, cooling modalities most commonly increase performance through masking of thermal sensation. However, the goal of cooling should be to change physiological responses, as those will have substantial effects on performance. A lower heart rate, or rectal temperature have been shown to increase exercise duration.^{7, 12, 17, 23} Manipulating thermal sensory input has its limits as shown in Tyler et al. study regarding neck cooling where the cooling collar was regularly replaced.⁴¹ Eventually the rise in internal body temperature will cause the distribution of blood to shift towards the periphery causing strain on the cardiovascular system and ultimately decreasing performance. The masking of thermal sensation should also be used with caution; without proper perception, an individual could ignore the body's natural signals of rising temperatures and experience heat illnesses like exertional heat stroke.

Based on the results of this review we suggest, ice vests as the best cooling modality option. This method provides the greatest covered surface area, and can provide adequate cooling temperatures. It should be noted that a mixed modality approach (i.e. utilizing one or more modalities) might have additive benefits over the use of a singular modality. Minett showed promise in performance increases when mixing both head and hand cooling, and DeMartini observed devices that covered upper and lower body provided greater cooling rates during a recovery period.^{13, 23} Future investigations should explore this method to find any further benefit. Not included in this review are the effects

of hydration status. Hydration has been shown to also play an important role in exercise performance in the heat and even increase performance in aerobic exercise.²

Sport medicine staffs should look at these “practical” cooling modalities critically. None of the presented modalities are recommended for the emergent cooling of hyperthermic athletes during heat illnesses. Cold-water immersion is the gold standard for emergent cooling and treatment of exertional heat stroke as it provides the fastest cooling rates.⁴⁵

There exists no cooling modality that can consistently provide positive benefits to athletes during exercise in an environment with uncompensable heat stress. Being properly acclimatized to hot environments is the recommended method to enhance thermoregulation and the functional capacity of physiological parameters, while attenuating decreases in exercise performance. After being properly acclimatized, the addition of cooling modalities may aid in performance enhancement through the masking of thermal sensory input, but offer no substantial physiological benefit.

XI. Bibliography

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Introduction

Athletics, and exercise in general, often requires effort that may push the human body to its limits. Additionally, there are a large number of factors that can either improve or lower the body's physiological exercise performance (e.g. training type, recovery, environment). Of greatest concern is when these additional factors place an individual at risk for medical illness.

Cold or hot environments, humidity, and high altitudes are all stressful surroundings in which exercise can take place, however, hot and humid environments are especially common for sporting events and its impact on the human body has been well studied.¹⁻⁹ A hot environment lowers the functioning capacity of the cardiovascular, thermoregulatory, and nervous systems, with environments usually above 25°C causing the body to absorb more heat than it can dissipate leading to adverse physiological effects.² All of these afflictions caused by heat have been shown to accumulate together and decrease exercise performance around 8-10% of maximal aerobic power.⁶ However, applying some form of cooling can delay or minimize these adverse effects.

If done successfully, cooling can slow the rise in body temperature, heart rate, and blunt perceptual measures of exertion and thermal sensations. However, for cooling to be successful there are many factors to be considered. One such item is the type of cooling modality utilized and its efficacy. Whole body cold water immersion provides fast cooling rates, and is the gold standard for the medical emergency of exertional heat stroke, but in non-emergent cases it can be inconvenient to the athlete.¹⁰ Therefore, most athletes potentially will turn to simple cooling products available on the market. Most cooling devices focus on the torso via ice vests or on the head and neck via cooling

collars or hoods; of those modalities, the most effective thus far have been those applied to the torso.^{4, 11-15} Additionally, the amount of surface area covered by the cooling modalities should also be contemplated. Barr et al. showing forearms can lower rectal temperatures, and DeMartini comparing cooling modalities with those having higher surface area coverage providing better cooling rates.^{12, 16} All of these items are vital for determining the components that need to be addressed for successful cooling outcomes.

Unfortunately, most practical cooling modalities have shown a reduction in responses of perception more so than physiological responses, such as decreases in rectal temperature during exercise. However, the goal of cooling should be to change physiological responses, as those will have longer lasting effects. Precooling has been shown to improve the maximal distance that can be achieved by long distance runners. This is accomplished physiologically by lowering the starting internal temperature of the runners thus allowing for a slower rise in temperature resulting in delay of fatigue that accompanies high internal temperatures.¹¹ Perceptual responses are significant; by changing one's perception of effort individuals can often improve performance by masking thermal perception and perceived exertion in a hot environment by manipulating the senses even though physiological parameters are not effected. This manipulation of the senses can lead to misinterpreting the body's signals, specifically rise in core temperature.¹⁷ If the mind cannot sense the rise in internal temperature, or still chooses to exercise at an intense rate, the body is at risk for severe exertional heat illnesses, such as exertional heat stroke.

The need for practical cooling in an athletic setting is paramount if safety and performance are to be maintained. The cooling method needs to be readily available,

easily accessible, and effective. Currently, there is not an easy, effective cooling device that can be worn during exercise to assist with body cooling. Recently, a cooling wristband has been released that, if effective, provides an easy, wearable cooling device that could potentially assist with cooling during exercise and recovery. To our knowledge this is the first portable device to apply cooling to the veins and arteries of the wrist. Cooling to this area of the body is novel in wearable devices and has not been validated for attenuation of physiological or perceptual effects during exercise and recovery. This device could fill the need for convenient cooling that could easily be placed on an individual without the need for equipment removal, or application to large surface areas on the body. There is potential for this to be applicable to exercising individuals or those at rest in a hot environment.

Therefore, the purpose of this study was to examine the physiological and perceptual effects of wearing a cooling wristband during a cycling exercise protocol with an uncompensable heat stress environment. A secondary purpose was to examine these effects during a post-exercise recovery period. Based off of the current literature, we hypothesize that the cooling wristband's effects during exercise will be on the wearer's thermal perception and perceived exertion.^{17, 18} Secondly, we hypothesize that during a recovery or cool down period there will be an attenuation of physiological parameters such as rectal and skin temperatures, and heart rate.

Methods

This study is a randomized, counterbalanced, cross over design involving 14 recreationally active male subjects between the ages of 18-35 years (mean (\pm SD); 22 ± 4 y) volunteered to participate across four exercise trials. Trials were performed in the

Human Performance Lab at the University of Connecticut in an environmental chamber with a temperature set to 40°C and 40% relative humidity. A certified athletic trainer was present during all exercise trials and recovery periods. For this study improvement is defined as any attenuation or lowering of physiological or perceptual variables. The recovery period was 30 minutes of passive rest in a thermoneutral environment.

Subjects

Subjects qualified for the study if they were recreationally active, which was defined as at least 30 minutes of exercise four to five days a week, were between the ages of 18-35 years, and had a maximal oxygen uptake ($\text{VO}_{2\text{max}}$) of $\geq 45 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$. Subjects were recruited from the local university and community. Subjects were excluded if they had a history chronic health problems affecting the ability to thermoregulate, fever or illness at the time of testing, musculoskeletal injuries, history of exertional heat illness, or had any medications known to alter body temperature. All subjects read and signed an informed consent form approved by the Institutional Review Board at the University of Connecticut prior to participating in this study. Medical history was taken from all subjects and approved by a medical monitor.

Familiarization

Prior to experimental trials, all subjects reported to the lab for a one hour familiarization trial. Upon arrival subjects provided a urine sample in a clean urine cup. Urine specific gravity (USG) (Atago Model N-1, Tokyo, Japan) and urine color were assessed to determine hydration status.¹⁹ A rectal probe was then self-inserted 10cm past the anal sphincter for internal body temperature monitoring during testing. Height was

measured to nearest 0.5cm with a tape measure, and nude body mass was also recorded to the nearest 0.01kg (Defender 5000, OHAUS, Parsippany, NY).

Percent body fat was calculated using skin fold calipers (Lange, Beta Technology Inc, Cambridge, MD) on a 3-site evaluation to measure skin fold thickness of chest, abdomen, and thigh according to Jackson-Pollock method.²⁰ VO₂max test was performed by all subjects on a Velotron cycle ergometer (RacerMate Inc., Seattle, WA) in a thermoneutral environment to ensure aerobic fitness. The test began with a slow cycling warm up and incrementally increased power output until volitional fatigue. Heart rate was monitored by a heart rate strap (T-31, Polar Electro Inc., Finland), and oxygen consumption measured with open circuit spirometry. A minimum of 45 ml·kg⁻¹·min⁻¹ was required of all subjects (Table 1.).

If the subject met the aerobic fitness requirements, they were then escorted to sit in the environmental chamber (Minus-Eleven Inc., Weymouth, MA) (~40°C, 30-50% relative humidity) without distraction for 10-15 minutes to equilibrate. Following equilibration, baseline perceptual indices were recorded. Perceptual indices include: Environmental Symptoms Questionnaire, Delayed Onset Muscle Soreness scale administered by paper and pencil, rating of perceived exertion (RPE), thermal sensation, thirst sensation, and perception of fatigue via patient reporting from a Likert scale.²¹⁻
²⁶Subjects then went on to complete the Balance Error Scoring System (BESS) barefooted on two surfaces: hard floor and foam pad.²⁷ Lastly, subjects completed two paper and pencil cognitive tests, including a Letter Digit Substitution Test and Trail Making Test.^{28, 29} Pittsburgh Sleep Quality Index and Karolinska Sleep Diary were taken to establish assessment of subjective sleep quality. Pittsburgh Sleep Quality Index was

only taken during the familiarization trial and recorded by paper and pencil. The Karolinska Sleep Diary was emailed to subjects the morning following any exercise trial. This questionnaire was used to track sleep habits and identify subjective effects on the amount and quality of sleep.

Exercise Trials

Subjects were asked to complete four exercise trials with a max of two trials per week to allow for adequate recovery. Due to the presence or absence of the wrist cooling device (Dhama Innovations Pvt. Ltd. Hyderabad Telangana, India) complete blinding of subjects and researchers to the intervention was not possible. The four trials were as follows:

- 1 wristband during exercise, and half of the subjects receiving a wristband during recovery (W_1)
- 2 wristbands during exercise, and half of the subjects receiving wristbands during recovery (W_2)
- No wristband during exercise, and no wristband during recovery (CON)
- Wristband only during recovery (REC)

Subjects reported to the lab in exercising attire (t-shirt, shorts, socks, and running shoes). Before arrival to the lab, subjects were asked to consume 16.9fl oz of water to ensure proper hydration. Urine color and USG were tested from a urine sample obtained upon arrival to confirm hydration status. If the subject was deemed hypohydrated ($USG > 1.020$) an additional 16.9fl oz was provided and then hydration was reassessed after a minimum period of 30 minutes. If the subject was moderately hypohydrated ($USG > 1.026$) the exercise trial was rescheduled for a later date. All subjects were required to

abstain from caffeine and alcohol for 24 hours prior to testing.^{30, 31} Nude body mass was recorded and a rectal thermometer (Measurement Specialties, Hampton, VA) was then self-inserted 10cm past the anal sphincter. Heart rate was monitored via heart rate strap (T-31, Polar Electro Inc., Finland). Skin temperature (T_{sk}) was assessed via skin temperature thermistors (iButtonLink Thermochron, Whitwater, WI) applied to four sites: chest, upper arm, thigh, and calf. A weighted mean of the four thermistors were then taken to determine mean body skin temperature using the Ramanathan equation³².

$$T_{sk}=0.3(T_{chest} + T_{forearm})+0.2(T_{thigh} + T_{calf}).$$

For the trials involving wristbands, each participant was designated a cooling wristband so that the same participant used that same wristband(s) for all trials. The wristband was used according to the manufacturer's instructions, which included placing 50mL of water on the device immediately prior to use, and attaching it to the wrist with cooling applied to the ventral side of the wrist, and turned on to the highest cooling setting. The device was periodically re-wetted with 50mL every 15 minutes per manufacturer's instruction.

Subjects then entered the heat chamber to equilibrate for 10-15 minutes. The exercise trial consisted of biking on a Velotron cycle ergometer between 50-60% of their individual VO_{2max} for 30 minutes. Following the 30-minute interval, wattage was increased to 70-80% VO_{2max} for a 15-minute interval. This interval was repeated three times for a total of 135 minutes. A fan blew on the subject at approximately 5mph to simulate wind speed. Physiological and perceptual parameters were recorded every 15 minutes. Environmental conditions and blood lactate were recorded every 45 minutes. Blood lactate was measured using blood lactate analyzer utilizing a small blood droplet

sample (Bio-Asia Diagnostics, Hong Kong, China). Testing continued unless one of the following four criteria were observed: (1) participant requested to stop, (2) rectal temperature (T_{rec}) $>39.99^{\circ}\text{C}$, (3) heart rate $>$ age-predicted maximum ($220-\text{age}$) for 5 consecutive minutes, or (4) trial was completed. Water was provided *ad libitum* throughout the trial.

Immediately after completion of the exercise trial, while still in the environmental chamber, perceptual indices, BESS, and cognitive testing were performed. Subjects were then escorted outside the heat chamber to sit quietly for a 30-minute recovery period in a thermoneutral environment. After the recovery period had lapsed, measurements of heart rate, T_{rec} , perceptual indices, BESS, cognitive testing, hydration, and nude body mass were repeated.

Data Analyses

All data were analyzed using the Statistical Package for the Social Sciences software (SPSS v.24 [IBM, Armonk, NY]). Descriptive statistics were conducted for all dependent variables: T_{rec} , skin temperature, heart rate (HR), RPE, fatigue, thirst, blood lactate, and thermal sensation. Furthermore, these variables were analyzed during the exercise trial, and after the recovery period respectively. A 2 x 4 (group x time) repeated measures analysis of variance was performed for each variable when analyzing the exercise trials. A paired samples T-test utilizing post exercise to post recovery delta values was used to analyze all post-recovery data. Significance was determined *a priori* at $p \leq 0.05$. Post-hoc tests were ran if any significance was found during the group by time analysis of variance. Cohen's d effect size was calculated to detail magnitude of changes between significant results.

Results

Fourteen recreationally active male subjects between the ages of 18-35 years (mean (\pm SD); 22 ± 4 y) volunteered to participate. Subject demographics are provided in Table 1. A complete list of environmental conditions, body mass losses, and workloads are provided in Table 2. One subject terminated exercise early after the 120-minute mark due to an elevated $T_{\text{rec}} (\geq 39.99^\circ\text{C})$. Because of this, data for all subjects after the 120 mark was not included in the analyses during exercise. Heat production and heat loss was derived through equations from Dennis and Nielsen.^{33, 34}

Table 1. Subject Demographic Information

| Characteristics | Mean \pm SD |
|--|------------------|
| Age (years) | 22 ± 4 |
| Height (cm) | 181.6 ± 6.9 |
| Weight (kg) | 75.4 ± 8.7 |
| Body Fat (%) | 10.7 ± 3.4 |
| VO ₂ Max (mL/min/kg) | 53.1 ± 7.2 |
| Watts VO ₂ Max (watts/kg) | 367.9 ± 76.9 |
| 55% Watts VO ₂ Max (watts/kg) | 203.3 ± 42.3 |
| 70% Watts VO ₂ Max (watts/kg) | 275.5 ± 53.8 |

Table 2. Trial information for all for four exercise interventions

| Trial Information | CON | W1 | W2 | REC |
|-----------------------------|--------------------|--------------------|--------------------|--------------------|
| Ambient Air Temperature (C) | 39.3 ± 0.6 | 39.7 ± 0.4 | 39.5 ± 0.4 | 39.5 ± 0.3 |
| Relative Humidity (%) | 39.7 ± 3.1 | 38.1 ± 3.0 | 37.9 ± 2.6 | 38.9 ± 3.2 |
| Water Intake (kg) | 2.2 ± 0.7 | 2.2 ± 0.8 | 2.0 ± 0.5 | 2.4 ± 0.7 |
| Body Mass Loss (% Kg) | -1.1 ± 1.0 | -1.2 ± 1.3 | -1.3 ± 0.8 | -0.9 ± 1.0 |
| Heat Production (kJ) | 2058.8 ± 435.8 | 2058.8 ± 435.8 | 2058.8 ± 435.8 | 2058.8 ± 435.8 |
| Heat Gain (kJ) | 2084.2 ± 435.7 | 2048.2 ± 435.7 | 2048.2 ± 435.7 | 2048.2 ± 435.7 |
| Heat Loss (kJ) | 1.6 ± 0.1 | 1.6 ± 0.1 | 1.6 ± 0.1 | 1.6 ± 0.1 |

Wrist Cooling During Exercise

Due to no statistical difference between groups W_1 and W_2 ($p > 0.05$) during exercise, the data from these groups were pooled together (W_p) when analyzing each variable during exercise.

Physiological Responses

We observed no significant interaction for the variable of T_{red} between CON (Mean: 38.09°C , 95% CI: $37.91\text{-}38.27^{\circ}\text{C}$) and W_p (Mean: 38.13°C 95% CI: $37.96\text{-}38.30^{\circ}\text{C}$) over time during exercise ($p = 0.856$). Skin temperature showed no significant difference between groups CON (Mean: 36.90°C , 95% CI: $36.77\text{-}37.06^{\circ}\text{C}$) and W_p (Mean: 36.84°C 95% CI: $36.63\text{-}37.05^{\circ}\text{C}$) over time for mean body skin temperature during exercise ($p = 0.481$). We observed no significant interaction between CON (Mean: 125bpm, 95% CI: 120-130bpm) HR and W_p (Mean: 130bpm, 95% CI: 124-135bpm) HR during exercise ($p = 0.308$). No significant difference in blood lactate was observed between CON (Mean: 1.79mmol/L 95% CI: 1.32-2.27mmol/L) and W_p (1.93mmol/L, 95% CI: 1.46-2.40mmol/L) for blood lactate during exercise ($p = 0.614$).

Perceptual Measures

No group by time interactions were observed for the perceptual variables of RPE ($p = 0.129$), thirst ($p = 0.566$), or fatigue ($p = 0.153$) between groups during exercise. However, the interaction between time points and groups for thermal perception approached statistical significance, but ultimately failed to reach our set standard ($p = 0.053$).

Wrist Cooling During a Recovery Period

Similar to the exercise trials, no differences were observed between W_1 and W_2 trials during recovery for any dependent variable. At the end of W_1 and W_2 exercise protocols, subjects were randomized into two recovery groups. One group continued to wear the wristband (W_{PD}) and the other group removed the wristband (W_{PN}) during the recovery period. As referenced before, REC group solely wore wristbands during the recovery period and not during the exercise trials. To observe the effect of the device, regardless of intervention, data from all groups wearing the device were pooled into the device-wearing group (DR). For groups not wearing the device, all data were pooled into the non-device wearing group (NDR). See Table 3 for a full summary of results during recovery. See Figure 1 for a flowchart of the subject grouping and associated abbreviations for the recovery analysis.

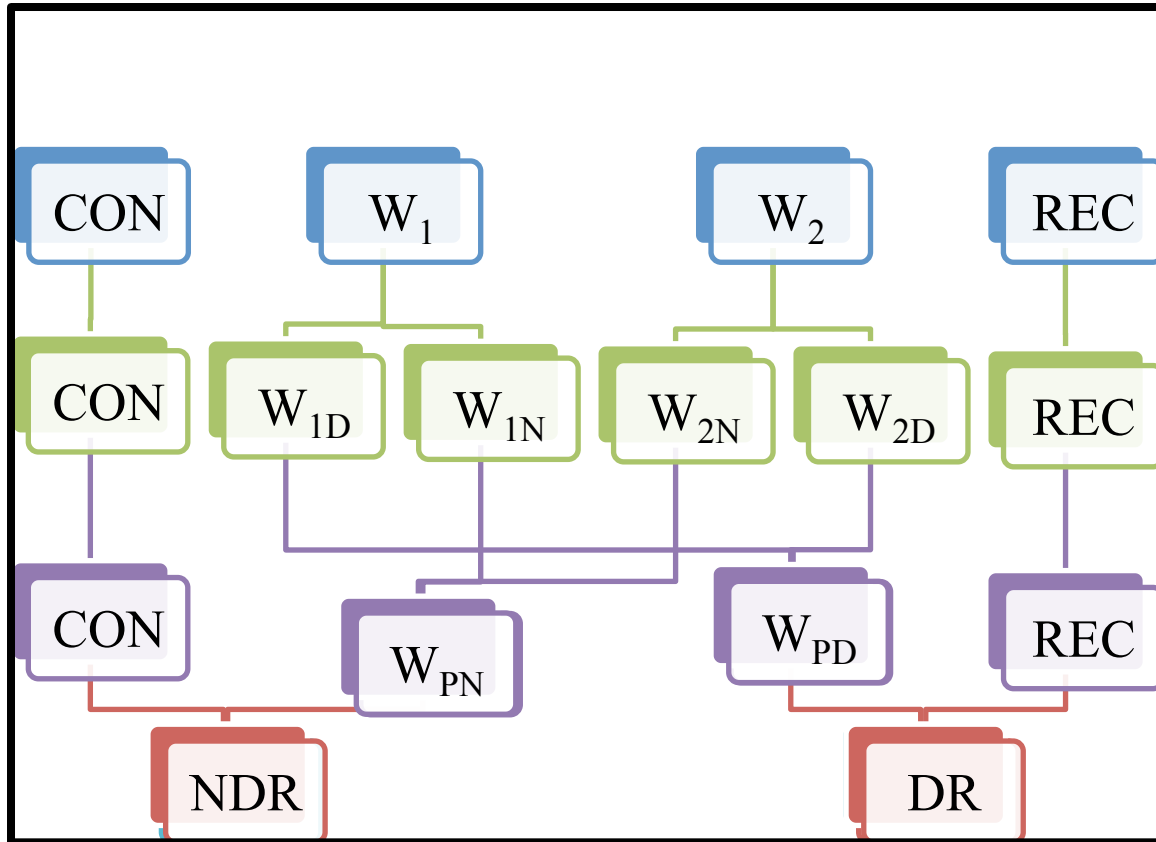


Figure 1. Flow Chart of Recovery Period Design and Trial Abbreviations.

First Level: Groups during exercise trials. Second Level: Groups during the recovery period. CON= Control of no wristband device, W_1 = One wristband device, W_2 = Two wristband devices, W_{1D} = One wristband device worn during recovery, W_{1N} = No wristband device worn during recovery, W_{2D} = Two wristband devices worn during recovery, W_{2N} = No wristband devices worn during recovery, REC= wristband devices only worn during recovery Third Level: Groups pooled together for analysis. W_{PD} = Groups wearing devices from exercise to recovery, W_{PN} = Groups wore no devices during exercise and not during recovery. Fourth level: Data pooled from all groups wearing and not wearing devices. NDR= No device during recovery, DR= device during recovery

Physiological Responses:

During the recovery period, significant differences were found in the magnitude of T_{rec} cooling for DR vs. NDR (Figure 2.) (Mean $0.33^{\circ}\text{C} \pm 0.51^{\circ}\text{C}$, $p = 0.010$, $d = 0.65$).

Additionally, differences were observed between W_{PN} and REC (Mean: $-0.27^{\circ}\text{C} \pm 0.31$, $p = 0.023$, $d = 0.72$) (Figure 3.) No differences were seen between groups when comparing skin temperatures. However, the comparison CON to W_{PN} groups for skin temperature

approached significance (Mean: $0.60^{\circ}\text{C} \pm 0.88^{\circ}\text{C}$, $p=0.06$, $d=0.96$). No significant differences were observed in any group comparison for heart rate during recovery.

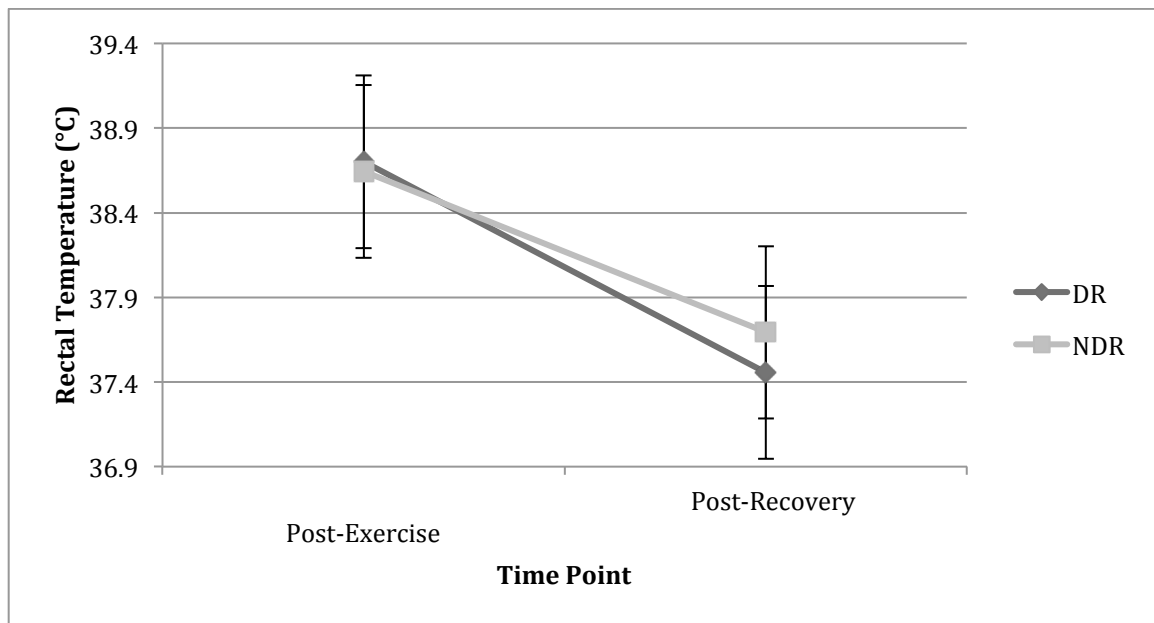


Figure 2. Change in T_{rec} between groups wearing cooling wristbands and those not wearing cooling wristbands during recovery.
 DR= All pooled data from groups wearing wristbands during the recovery period ($W_R + W_{PR}$). NDR= All pooled data from groups not wearing wristbands during the recovery period ($CON + W_{PN}$).

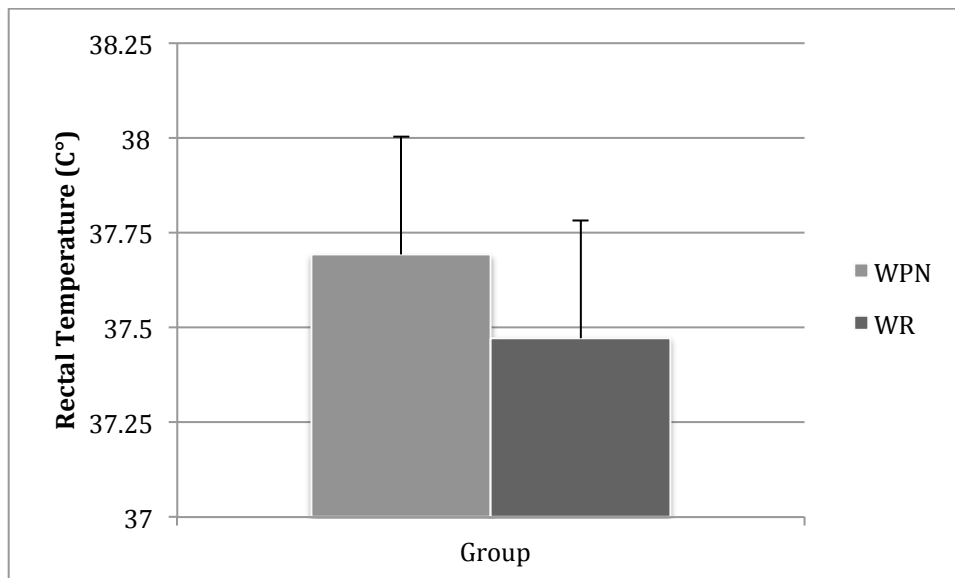


Figure 3. Final T_{rec} when Dhama wristband was worn solely during exercise or solely in recovery.
 REC= wristband during the recovery period only, W_{PN} = removing wristband after the exercise protocol.

Perceptual Measures:

No differences existed between groups for RPE, fatigue, thirst, or thermal sensation during the recovery period ($p > 0.05$). Neither cognitive test, trail making or letter digit substitution, showed any significant interaction ($p > 0.05$). Significant differences were observed for the BESS measurement in the single leg stance on a foam surface when comparing REC and W_{PR} groups (Mean 3.00 ± 3.44 , $p = 0.006$). A trend was observed in the tandem stance on a foam surface when comparing NDR and DR groups (Mean 6.85 ± 2.96 , $p < 0.001$).

| | T _{Rec} (C°) | T _{Sk} (C°) | HR (bpm) | Thermal Sense (Avg. Rating) | Trail Making (Seconds) | Letter Digit Substitut ion (# of Letters) | BESS (# of Errors) |
|--------------------------------------|-----------------------|----------------------|-----------------|--------------------------------------|------------------------------|---|--------------------------------------|
| 1. REC vs. W_{PR} | | | | | | | |
| Mean ± SD | .03 ± 0.41 | -2.94 ± 10.30 | 6.70 ± 26.50 | -0.10 ± 0.74 | 7.90 ± 21.60 | -2.90 ± 7.87 | SL: 4 ± 6 TS: 2 ± 2 |
| p Value | p = 0.821 | p = 0.390 | p = 0.445 | p = 0.678 | p = 0.304 | p = 0.274 | SL: p = 0.006 TS: p = 0.132 |
| 2. CON vs. W_{PN} | | | | | | | |
| Mean ± SD | -0.01 ± 0.27 | 0.60 ± 0.88 | 4.30 ± 15.81 | 0.10 ± 0.21 | -5.56 ± 18.66 | 0.60 ± 6.36 | SL: 1 ± 7 TS: 3 ± 3 |
| p Value | p = 0.893 | p = 0.06* | p = 0.412 | p = 0.168 | p = 0.371 | p = 0.772 | SL: p = 0.242 TS: p = 0.121 |

3. REC vs. W_{PN}

| | | | | | | | |
|------------------|-----------------|----------------|------------------|----------------|-----------------|-----------------|------------------------------------|
| Mean ± SD | -0.27 ± 0.31 | 0.42 ± 0.90 | -8.40 ± 17.13 | 0.30 ± 0.79 | 1.13 ± 21.40 | -0.10 ± 5.70 | SL: 3 ± 7 TS: 2 ± 3 |
| p Value | p = 0.023* | p= 0.170 | p = 0.155 | p = 0.260 | p = 0.871 | p = 0.957 | SL: p=0.075 TS: p = 0.063 |

4. NDR vs. DR

| | | | | | | | |
|------------------|----------------|----------------|------------------|-----------------|------------------|----------------|---------------------------------------|
| Mean ± SD | 0.33 ± 0.51 | 0.16 ± 0.93 | -1.70 ± 33.74 | -0.38 ± 1.15 | -0.21 ± 14.92 | -1.3 ± 8.89 | SL: 1 ± 7 TS: 7 ± 4 |
| p Value | p =0.010* | p= 0.169 | p = 0.824 | p = 0.160 | p = 0.953 | p = 0.521 | SL: p = 0.290 TS: p < 0.001* |

Table 3. Summary of recovery results between groups wearing and not wristbands
 “*” denotes findings with significance. W_R= cooling wristband during recovery period only. W_{PR}= cooling wristband worn during both the exercise period and recovery period. W_{PN}= cooling wristband worn during the exercise period, but not the recovery period. CON= control trial, no DHAMAsport wristband worn at any time point. DR= all cooling wristband recovery data across all groups. NDR= data from trials without cooling wristband SL= Single Leg stance during the BESS testing, TS= Tandem stance during BESS testing.

Discussion

This cooling wristband is a novel cooling device that applies cooling to the ventral side of the wrist. This is the first device, to our knowledge, that applies cooling specifically to this area of the body. Past devices, garments, and techniques commonly apply cooling to body areas such as head, chest, neck, and palms. The aim of this study was to study the physiological and perceptual effects of this cooling wristband device applied to the ventral side of the wrist during exercise. In addition, we also observed the

effects of the cooling device on variables during a 30-minute recovery period following the exercise protocol.

The key finding in this study was that wearing a cooling wristband during a 30-minute recovery period following intense exercise in uncompensable heat stress lowers the wearer's T_{rec} faster than passive rest. In our two comparisons (Figures 1 & 2) we found a mean reduction of 0.33°C difference between the DR and NDR groups in T_{rec} . The cooling rate for the DR group was 0.04°C/min and passive rest was 0.03°C/min. The small cooling applied by the device on the ventral side of the wrist, closest to the veins, allowed for the blood to be cooled and return centrally. However, it does not have a very clinically significant rate of cooling. Additionally, from our analysis we found that there is no difference between wearing one or two wristbands during exercise or recovery.

As hypothesized, no physiological variables were decreased or attenuated for any condition during the exercise protocol. This is in line with most literature on practical cooling modalities.^{1, 4, 11-15, 17, 35-38} For example, in order for a change to be observed in T_{rec} , the cooling modality must overcome the metabolic heat production as well as the environment. During exercise with uncompensable heat stress in the current study, the average heat gains (2048kJ) and losses (1.6kJ) by subjects were identical throughout all four trials. The device likely could not provide the cooling temperatures necessary to lower a subject's T_{rec} during exercise. When changes are observed in T_{rec} from a cooling modality it is commonly due to sizeable pre-cooling, or large surface areas being covered.^{11, 12, 34} Thermal sensation has been shown to manipulate an exerciser's performance when exercising in the heat, however, perception of thermal sensation did not reach significance in the exercise trials where the wristband was applied.^{17, 39, 40}

During recovery, we examined four different comparison groups across physiological, perceptual, and cognitive variables. Our first comparison examined if wearing the cooling wristband during exercise, as well as recovery, increases the device's impact on recovery. From our comparison of REC and W_{PR} groups, we found that wearing the device during exercise does not provide any additional benefit to recovery. Likewise, our comparison of CON and W_{PN} groups showed that wearing the cooling device only during exercise does not ultimately impact recovery. Our third comparison examined the relationship between REC and W_{PN} to reveal if wearing the wristband only during exercise or only during recovery is more beneficial than the other. Our findings indicate that recovery provides the most benefit to the wearer. Our last comparison studied the relationship between NDR and DR groups. Regardless of exercise intervention the DHAMAsport wristband does improve recovery as shown by the lowering of T_{rec}. The findings of this study may indicate that when the body is recovering following the termination of exercise, cooling applied to a small area such as the wrist can proliferate the drop in T_{rec}. This follows similar research that was conducted by Adams et al. that showed palm cooling in both hands following exercise in the heat also could aid in the reduction of T_{rec}.⁴⁰

While this study was conducted for athletic purposes, attention should be drawn to applying this cooling modality in the work force. Research has been conducted on cooling modalities for laborers such as firefighters, who are constantly exposed to high temperatures.¹⁶ In an article by Barr, forearm cooling via immersion was executed over a 15min break into 19°C water, and lowered rectal temperatures ~0.4°C. The experimental group's drop in T_{rec} remained lower throughout the second bout of simulated firefighting

activity.¹⁶ In the present study, we did not expose our athletes to an additional bout of exercise so assumptions cannot be made about the effect it would have. However, other cooling modality research suggests that if a rectal temperature is lowered during a warm-up or resting period, temperatures will remain lower in the beginning phases of exercise.^{11, 35} Additionally, Yeargin used 5°C water for forearm immersion of 15 minutes and found cooling rates of 0.10°C/min for a total of about 1.5°C. Note that this study used colder temperature of water than in most research on cooling which may indicate why just forearm submersion provided those cooling rates.⁴¹

The investigated device did not have as impressive of cooling rates as forearm immersion into ice water (0.04°C vs. Yeargin 0.10°C), but still managed to decrease rectal temperatures. The current device does not require the removal of equipment and can be worn while on the job. While our device showed no benefit while being worn during exercise in an uncompensable heat stress environment, it remains unclear if the device would have effects during lower intensity exercise or passive heat exposure that a laborer might be placed in. This is an area of future research worth exploring as the convenience may be worth the investment.

Compared to most literature evaluating cooling modalities, our exercise protocol was performed under a very stressful environment of 40°C and 40%RH. This represents an extreme environment in which exercise is taking place, and could explain why physiological variables were not affected by the intervention, as the device may not have been able to overcome the heat produced by the environment as well as metabolic heat production.² To cool the body during exercise in uncompensable heat stress, the heat loss must outweigh the heat gain, and the surface area covered and amount of cooling applied

by the device may not have been sufficient.² As per the manufacturer's manual, the wristband device is able to apply up to 7.2°C of cooling. The average heat gained by subjects during the exercise trials was 2048kJ, and the heat loss was 1.6kJ (Table 2.). This displays that the either the device's surface area was not sufficient to over come the heat gain, or the surrounding environment temperature was too high for the device to compensate. Conversely, this amount of cooling and surface area was enough to aid in the lowering of rectal temperatures during a 30-minute recovery period. Studies should be done to see if this device has further benefits under milder conditions and perhaps a less intense exercise protocol.

A limitation to this study is the sample population consisted only of recreationally active males. Studies should be done to see if the same effects occur in women, or with persons with smaller body masses. Future research should also focus on a mixed modality approach, which has shown promise in the literature.^{12, 35, 42} Researchers should now include wrist cooling into their mixed cooling modalities to analyze any potential benefits it may add. The usefulness to other populations such as laborers like firefighters or construction workers who also are exposed to high temperatures should be evaluated.

There still exists the need for a practical cooling modality that can attenuate the negative physiological and performance effects of exercising in the heat. Thus far, cooling modalities have proved their worth in aiding with recovery, including this wristband. Wrist cooling could be an option for cooling when other modalities are infeasible, whether due to space or time. One such advantage to wrist cooling is the requirement for minimal equipment removal, and the simplicity of just applying one device. However, this may not be the greatest option for athletes based on our results

during the exercise trial providing insufficient cooling. Other populations, such as laborers, could potentially benefit from this novel cooling device based on our recovery portion where we saw positive results such as a lowered rectal temperature after exposure to uncompensable heat stress. Cold-water immersion remains the cooling method with the highest rate of cooling, and is the gold standard for treatment of exertional heat illnesses.¹⁰ No cooling modality should be used in place of cold-water immersion, especially for exertional heat stroke.

Conclusion

This study is the first to investigate the effects of wrist cooling via a wearable wristband on physiological and perceptual variables while exercising in an uncompensable heat stress environment and during a recovery period. Our results suggest that regardless of if the cooling wristband is worn during exercise, when worn during recovery it can lower rectal temperatures faster than passive rest. No physiological or perceptual benefits were seen when wearing the wristband during exercise. Possible applications for this would be half times of sporting events, breaks between competition, and immediately following exercise in the heat. Uses in other populations exposed to high environmental heat conditions should be studied. However, consideration on utilizing the wrist band over other methods that provide greater rates of cooling, such as cold-water immersion, should be taken. The authors do not suggest this device be used in the prevention or treatment of hyperthermia or exertional heat illnesses. Wearable cooling modalities remain an area that should continue to be explored due to the potentially advantageous effects such a device might have on decreasing internal temperatures of physically active people training in the heat.

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